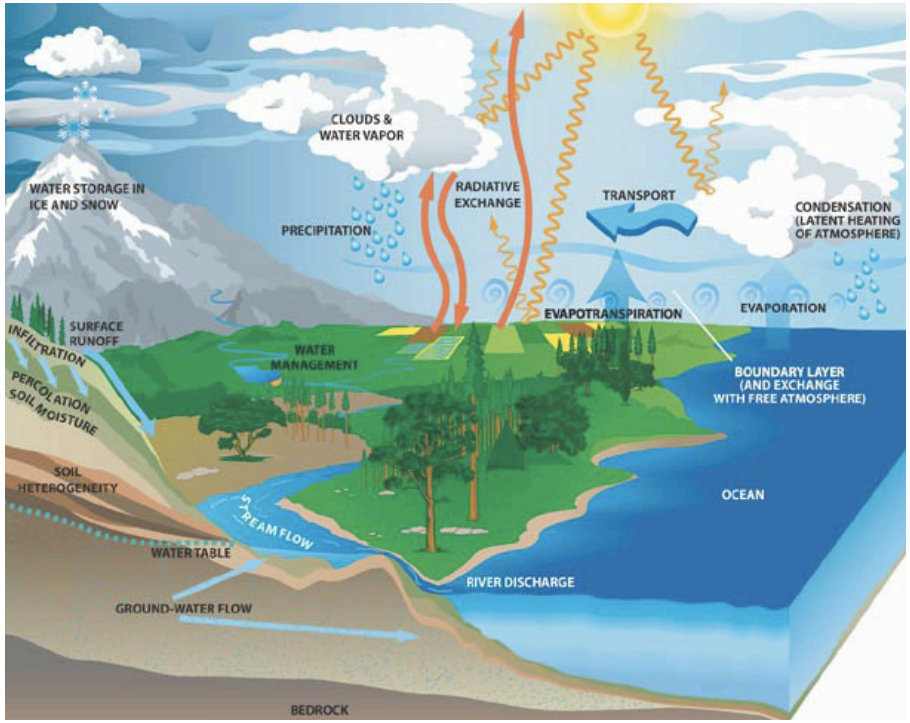
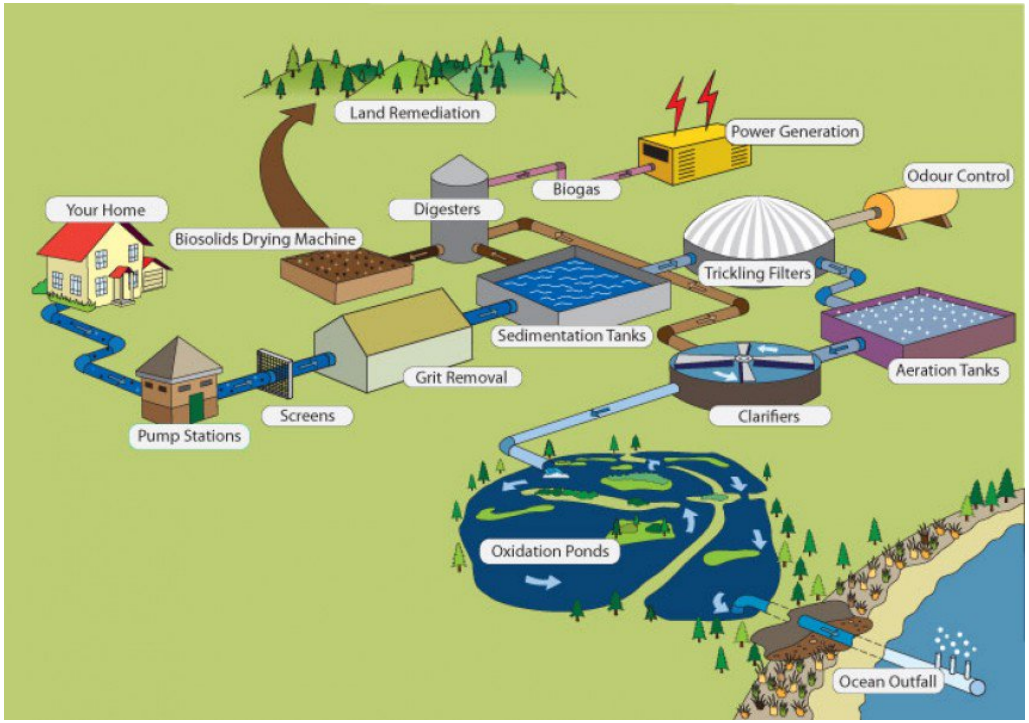
Recovery of Energy from Wastewater Treatment Plant Effluent Discharge to Seawater



Water Cycle



Waste Water Cycle

Energy Derived From the Discharge of sewage treatment effluent into Saline Waters

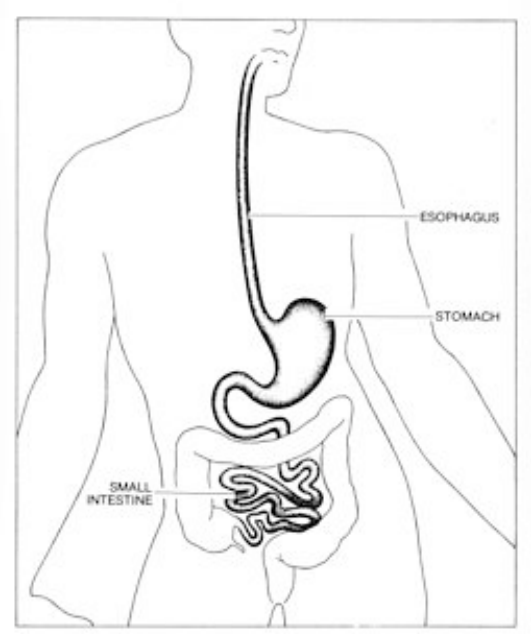
Pressure Retarded Osmosis

- Forward osmosis (FO) provides a method of harvesting the osmotic potential difference between fresh and saline waters to produce electricity.
- FO occurs any time fresh water and saline water are placed on opposite sides of a semi-permeable membrane.
- The osmotic potential difference between the two liquids causes water to flow naturally from the freshwater side of the membrane to the saline side.
- If the saline side is contained the pressure will increase until it equals the osmotic pressure of the saline solution.
- This pressure can then be used in a turbine to produce electricity.

Forward Osmosis

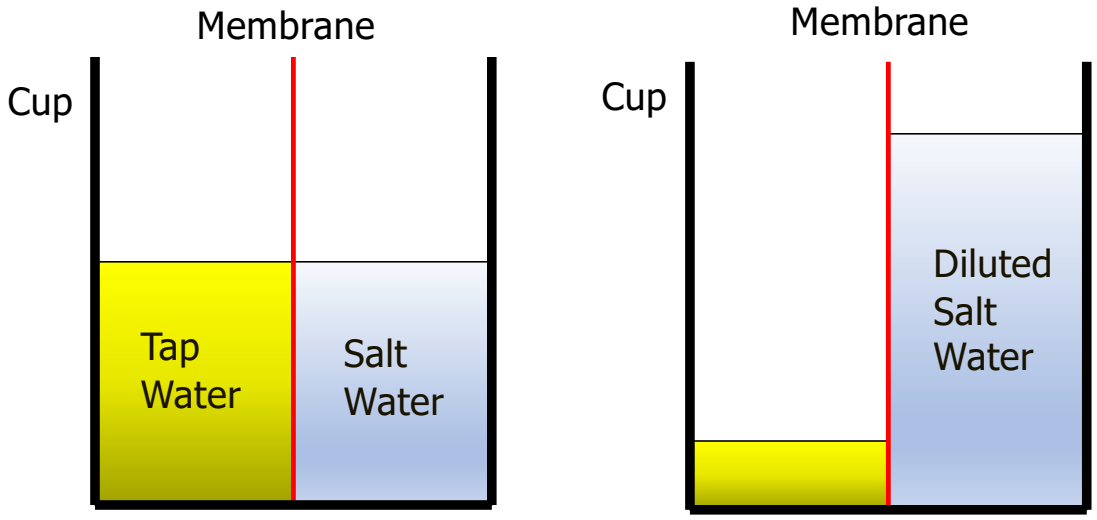
A Biomimetic Technology

Human Intestine Model

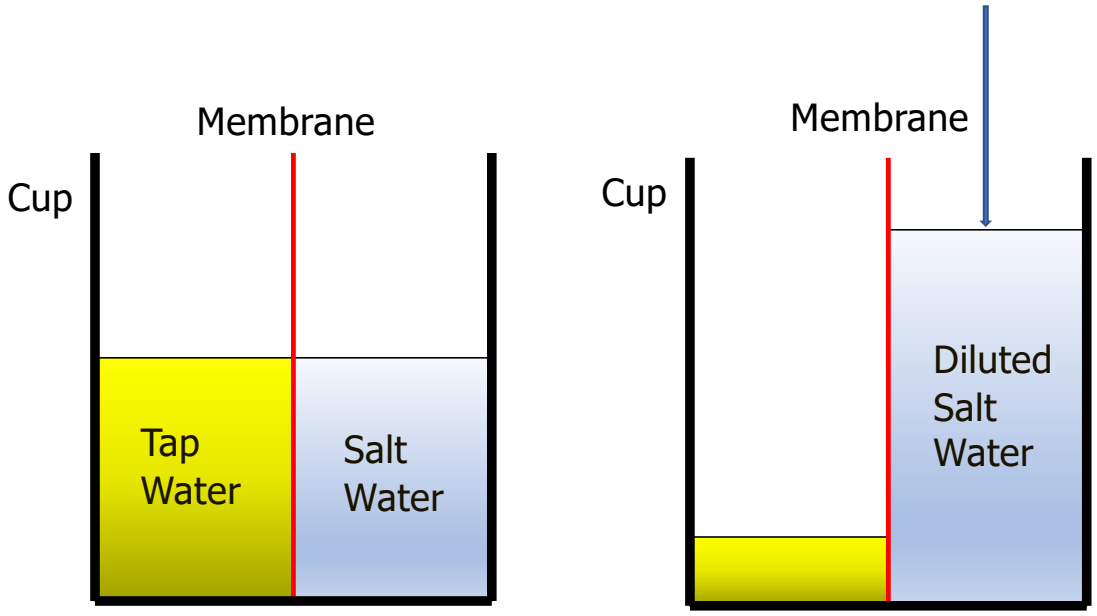


Plant Root Zone Model

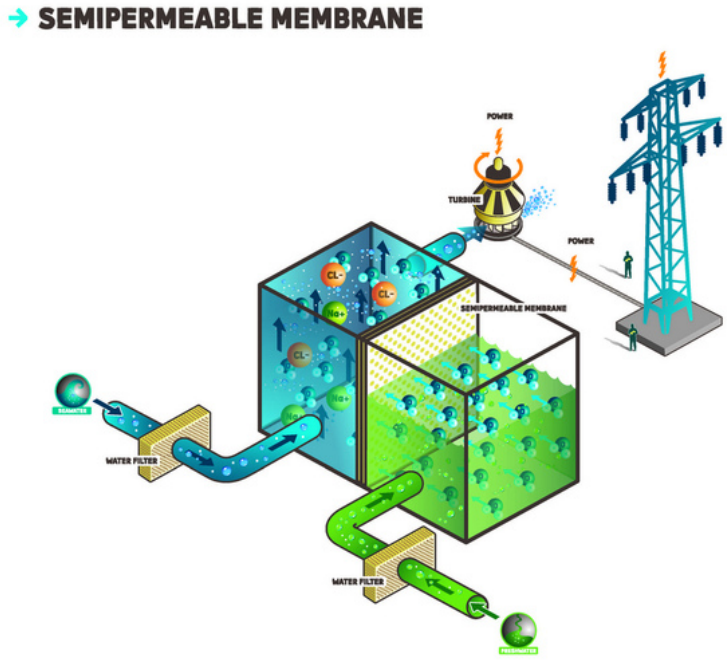
Forward Osmosis



Forward Osmosis

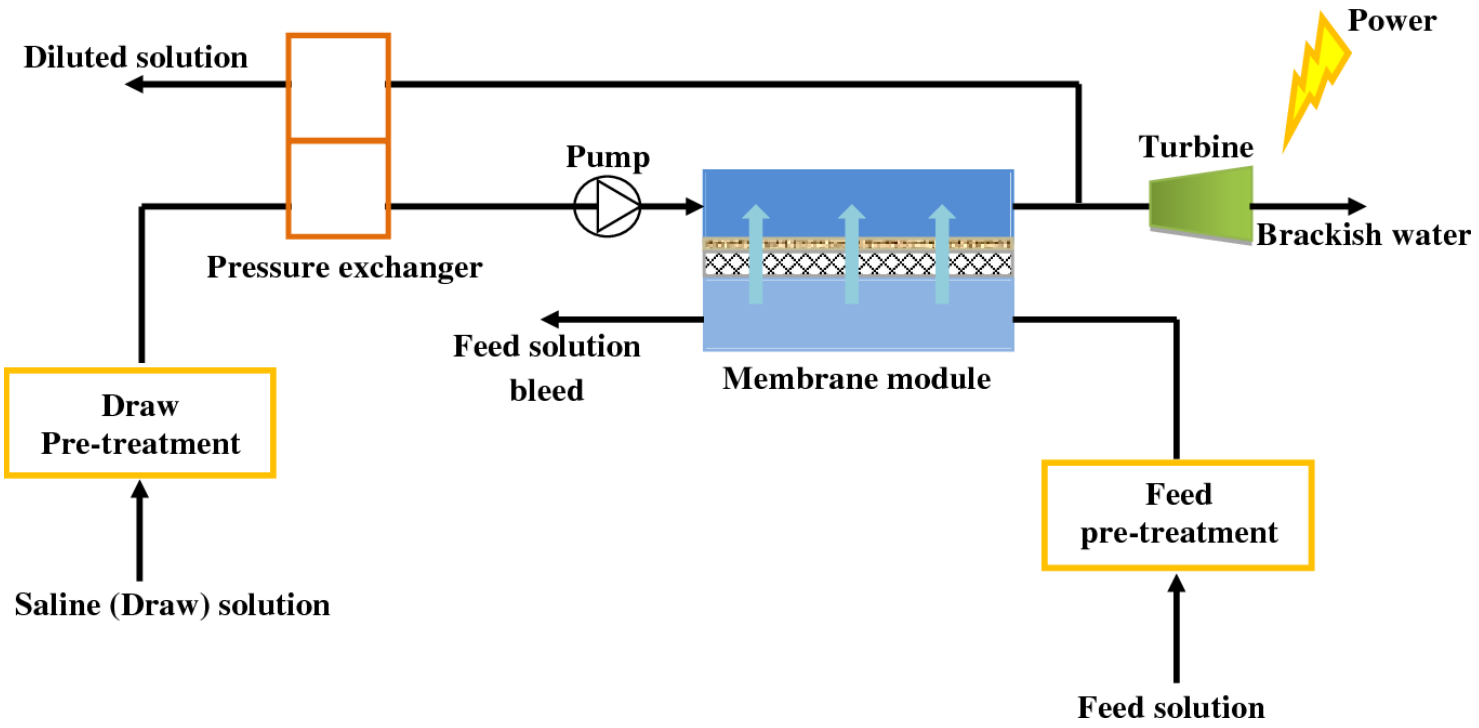


Osmotic Power - Statkraft



The worldwide potential energy of this resource for all rivers that discharge into saline bodies of water is reported to be in excess of 1600 tera-watt-hour per year.

Pressure Retarded Osmosis



- If the saline water is seawater, the pressure difference can reach as high as 410 psi.
- This pressure can be harvested as hydraulic power, similar to that of a hydroelectric dam.
- This system is referred to as pressure retarded forward osmosis (PRO) and can be used anywhere fresh water mixes with saline water.

California Rivers That Reach the Ocean

Klamath
Eel
Russian
San Joaquin/Sacramento
Salinas

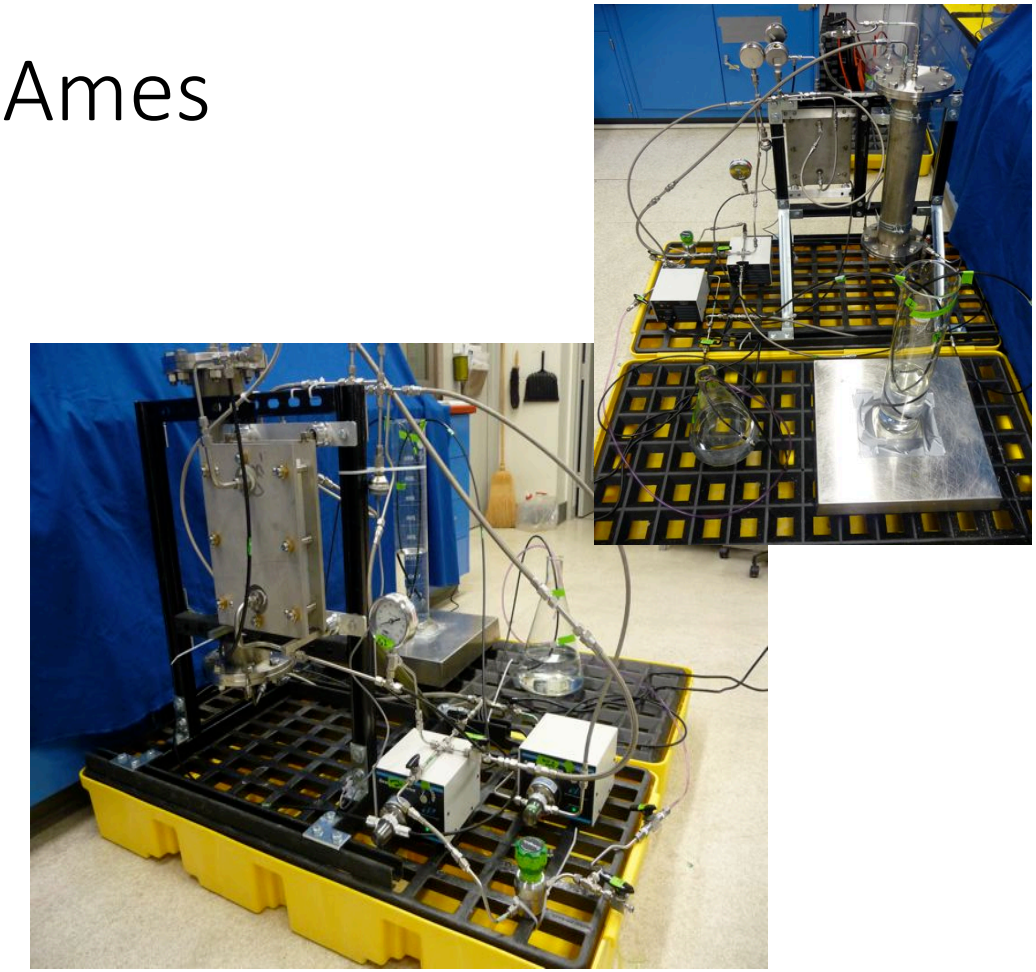
- In the State of California alone 1,350 million gallons per day of treated municipal wastewater is ultimately discharged into the Pacific Ocean.
- Using PRO, this represents about a 26-megawatt resource. At $0.10/kW-hr this has a value of about $14M/year.
- In addition, the proposed approach would also purify wastewater to tertiary standards resulting in the decreased release of nitrogen and endocrine disrupting compounds into the environment.
- The value of this concurrent water purification and energy production could offer a substantial benefit to California.

PRO Tertiary Treatment

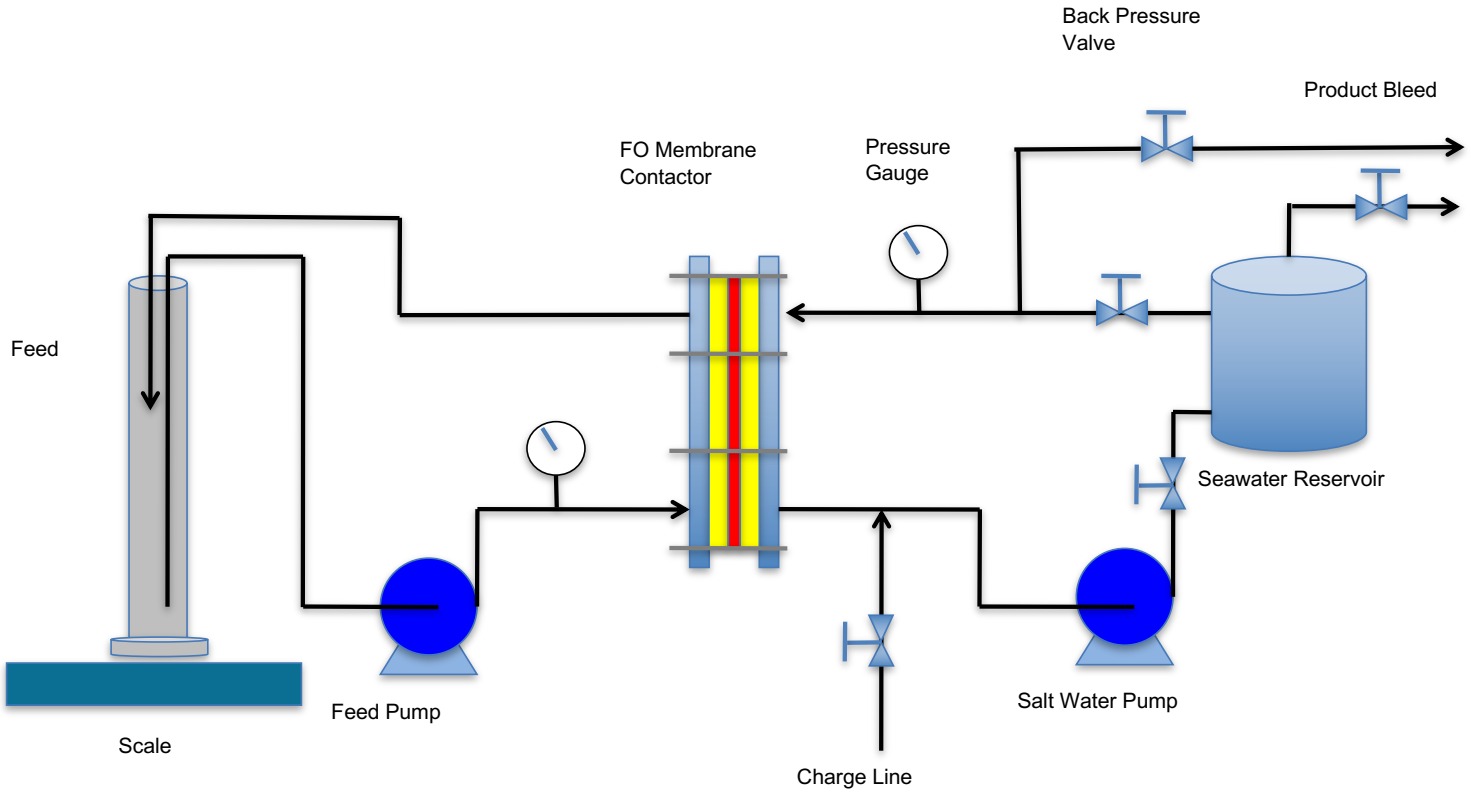
- In addition to the electricity produced, the PRO also provides tertiary treatment of the wastewater treatment plant's outfall.
- It removes organics, salts, minerals, metals, nitrates, phosphates, solids, bacteria and viruses.
- The combination of PRO and tertiary treatment provides the mutual benefit of sustainable power production and advanced wastewater treatment.

PRO Testing at NASA Ames

- System was tested in batch operation mode.
- Feed was secondary treated wastewater from San Francisco wastewater treatment plant.
- Osmotic agent was simulated seawater.
- Membranes were Hydration Technologies cellulose triacetate with high solids spacers.
- Operating pressure was 62 psi.



PRO Test Stand Flow Diagram



Results

- NASA PRO-TT testing at 62 psi gave power densities ranging 0.84 W/m^2 at start to 0.4 W/m^2 at the finish.
- This indicates an average volumetric power density of 0.12 W-hr/L (0.46 W-hr/gal), when projecting power potential in terms of input flow.

- Low-pressure power densities reported in the literature range from 2.3 to 0.11 W/m2 [1].
- High pressure power densities reported in the literature range from 4W/m^2 to 0.11 W/m^2 [11, 12, 13].

Water Treatment

- The NASA PRO-TT test also demonstrated the ability of PRO to perform tertiary treatment.
- Chemical analysis of the feed and product indicate that the process reduced all measured contaminants to below 0.5 ppm, with the exception of Na+ and Cl, which were used to simulate seawater.
- Nitrate and phosphate levels were reduced by 99% and 93% respectively.
- Non-purgeable total organic carbon (TOC) was reduced by 96%.
- Ammonium levels were reduced by 87%.

Advanced Membranes

- The membranes used in the testing were commercial off the shelf with flux rates of 2 LMH.

- Testing of in -house developed lipid membranes has shown higher flux rates

Membrane ID:	LMH	STDEV	SE
SFT6715A	12.06	5.39	1.24
SFT6715B	10.45	5.04	1.59
SFT6715C	12.08	7.76	2.59

Predicted Future Performance

- A five times increase in flux will roughly increase the power density by five times.
- A case study for a treatment plant with 167,000,000 gal/day of effluent is provided in the Table below.

Case Study	MW	$OpRev	$CapEX	Years to Payback
Commercial Membranes	3.2 MW	+$2.8 M	-$12M	4.3
Advanced Membranes	16.0 MW	+$14 M	-$12M	1